Synopsis for Ph.D. Thesis

Title of Proposed Work

STUDY ON NEUTRAL DENSITY FILTER WITH COMBINATION OF METALS FOR BETTER NEUTRALITY

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Introduction:

Neutral density filter is filter that is intended to equally reduce the intensity power of incident beam of light evenly over a desired spectral region (For visible region 400nm-700nm).

Neutral density filter are specified by the optical density (OD) of the filter, which is the negative of the comman logarithm of the transmission coefficient.

OD = -log T

Where $T = Io/I_T$

Wherein: Io = incident light intensity

I_T = transmitted light intensity

Neutral density filter can be produced either bulk absorption like glasses or thin film optical coating. They are characterised by their percent transmission range of wavelength where transmission is constant. A Neural density filters to be employed in the visible region of the spectrum are commonly constructed of absorbing filter glasses.

Any metal do show absorption which can be used to reduce transmission however due to adhesion and thickness etc.

Conventional neutral-density filters are made up of Inconel (an alloy of nickel, chromium, and iron) or Nichrome (an alloy of nickel and chromium) films on a dielectric substrate, such as germanium. The transmittance of filters made of Inconel or Nichrome is very flat for optical densities less than or equal to 2. For filters with optical densities greater than 2. however, the transmittance can vary by orders of magnitude.

The neutrality of the transmittance can be improved further by using correction layers or by adjusting the relative composition of copper and nickel. Filters of OD greater than four with a variation of less than one can be made using copper-nickel films. A thin dielectric layer, such as SiO_2, may be deposited on top of the alloy film to protect it from oxidation.

This is classify in two categories: Absorptive ND filters and Reflective ND filters. It can prevent damage to some detectors and also light exposure in camera.

Neutral-density filters are widely used in spectrophotometric and photography and instrumentation.

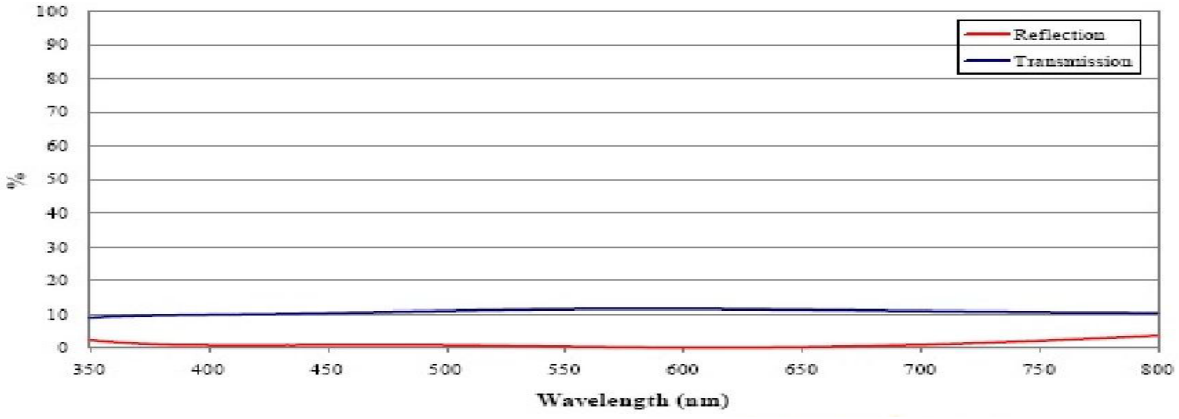


Fig.1 Performance coating curve of neutral density filter

Source:https://www.edmundoptics.com/knowledgecenter/application-notes/optics/optical-filters/

Review of literature-

National and International status:

1.Mary Banning (1947) : A short review of the available neutral density filters is given, with emphasis placed on the evaporation of Chromel A to form a film of any practical density that has neutral transmission throughout the visible and into the infra-red and ultraviolet regions. These films are simple to make and have proved to have good durability, resisting corrosion and rough handling.
These neutral films are about as hard as pure chromium and withstand a great deal of punishment, especially if heated to approximately 200'C after evaporation. An opaque Chromel A film can be used in most cases as a substitute for chromium, as for a mirror or a backing for aluminum. This is often desirable because Chromel A evaporates from tungsten more simply and more quickly than pure chromium.

2. David H. Cushing(1989): The substrate may be made of a wide variety of materials, including glass for the visible (VIS) range, quartz forthe ultraviolet (UV) and VIS ranges, sapphire for the vacuum UV range of approximately 1700-2000A certain plastics such as acrylics and polycarbonates for the VIS range, and certain inorganic crystals such as magnesium fluoride for use in the far UV from approximately 1200-2000A. The transmission characteristics of possible substrate materials are generally known and in any case are readily measurable. For filters usable in the UV range above approximately 2000A preferred substrate material is quartz.
The metallic and dielectric materials employed. In these examples, INCONEL 600 (TM) is taken as the metal alloy. Hafnium oxide, having an index of refraction of 1.85, is taken as the dielectric material contacting the layers of the metal alloy. The initial layer of dielectric material in contact with the substrate is taken as aluminium oxide having an index of refraction of 1.63, and the outermost layer of dielectric material is taken as quartz having an index of refraction of 1.46.

3.Keith E.Bennett(1990) : A neutral density filter is made by providing a substrate including a volume absorber having a first density and having an uneven first attenuation characteristic, and providing for a substantially constant attenuation of light by depositing on a backside of the volume absorber a thin-film attenuator having light reflective properties attenuated by the volume attenuator, having a second density and a second attenuation characteristic substantially complementing the first attenuation characteristic to provide the neutral density filter with a substantially constant attenuation at a density substantially equal to the first and second densities. The volume absorber and thin film attenuator are positioned so that incoming light first traverses the volume absorber and then the thin-film attenuator. An antireflection coating may be deposited on a front side of the volume absorber.

4. Bittar *et al.* (1992): In this paper use of metal-insulator films as neutral density filters for spectrophotometric calibration in the UV and visible ranges. We present a theoretical approach to the design of such filters and show that the correct selection of starting metallic material as well as filling fraction and filter thickness is important in obtaining the required profile. A comparison

between theoretical and experimental Ni/SiO2 films show the suitability of this approach to designing neutral density filters for the 200-800-nm wavelength range and beyond

The main spectral requirements for such filters are as follows:
(1) Slow variation of the transmittance with wavelength over the 200-800-nm range.
(2) Transmittances between 0.70 and 0.20, which may be easily produced.
(3) Low reflectance over the full wavelength range

5. Frenkel et al. (1994): A new concept for the design of broadband (2-25 ,um and beyond) neutral-density filters in the infrared region without etaloning effects is proposed and demonstrated. One important aspect of the technique is to use metallic-thin-film (10-200-nm-thick) multilayer combinations deposited onto different substrates (ZnSe, CdTe, Lexan). Neutral-density filters with optical densities as high as 4 are designed and built in the broadband region (2-25 **/.m).** Another key innovation is the use of ultrathin substrates (-100 nm thick) for elimination of 6taloning effects normally present in thick (>0.5-mm) substrates. Neutral-density filters with such ultrathin substrates are also designed and investigated.

6. Zhang et al. (1997): We have developed a facility for measuring the transmittance of optical filters at a wavelength of 1064 nm, using a Nd:YAG laser, a power stabilizer, and linear photodiode detectors. A direct measurement method was used for filters with optical densities ~OD's! less than or equal to 4, and a reference substitution technique was used for filters with OD's as great as 10. The apparatus and data-acquisition system are described. Measurement results for a set of filters are presented. The expanded uncertainties for the measured OD and deduced absorption coefficient are determined through a detailed analysis of all the uncertainty components.

7. Glenn Lefever-Button et al. (1998): In this paper we study a set of neutral density filters covering the optical density range of OD I through OD 10 has been designed and constructed for use as calibration and reference filters in the infrared. The filters are optically flat, with a variation of at most one OD within the spectral range of2 jim to 25 rim. Many filters exhibit better than 0.5 OD variation. They each are constructed of a metallic film supported by an ultrathin (100 nm) polyimide film substrate that minimizes the chance of etaloning within the filter. The polyimide substrate is sufficiently robust to withstand handling in a laboratory environment and provide long lived performance. This paper details the theoretical model used to determine appropriate materials for these filters, as well as the vacuum deposition processes developed to construct them.

8. Zhang et al. (1998): A neutral-density optical filter has a dielectric substrate and a film consisting essentially of copper and nickel. The film is preferably formed of Constantan, which is 55% copper and 45% nickel. The filter achieves a high optical density with a low spectral variation.

9. Kunii (2003): A neutral density filter has a multi-layer Structure of thin films laminated on a Substrate made of a transparent mate rial. The multi-layer Structure contains a transparent thin film composed of a dielectric material effective to transmit the incident light and a non-transparent thin film effective to absorb a part of the incident light. The non-transparent thin film is composed of a metal material which is deposited by Vacuum evaporation. The non-transparent thin film contains an oxide of the metal material, which is generated during the Vacuum evaporation by

introducing a gas containing an oxygen while maintaining a vacuum degree in a range of 1x10 Pa to 1x10Pa, and which is deposited concurrently with the metal material.

10. Okami et al. (2007): An absorption type multi-layer film ND filter having a Substrate and an optical multi-layer member consisting essentially of metal layers each composed chiefly of nickel (Ni) and dielectric layers each formed of any one of SiO, Al-O and a mixture of these; the layers being alternately layered on the substrate. An Ni type metallic material having a small wavelength dependence of transmittance in the visible spectral range is used in the metal layers serving as light attenuation layers, and this enables materialization of an ND filter which can attain transmittance attenuation that is flat for wavelengths.

11. Ciurea (2007): An apparatus and method that extend the graduated neutral density filter approach by implementing an in-camera adjustable neutral density filter are described. The adjustable neutral density filter is implemented by the means of a transmissive LCD. The transmissive LCD is controlled to form a mask image. This mask image is able to be computed using an acquired signal wherein the acquired signal is then inverted and blurred. In an embodiment, a splitter and an additional sensor are utilized to acquire a split signal and then modify the split signal for use as the mask image. The other split signal is filtered through the mask image and transmissive LCD. Images with a high dynamic range compression are ultimately captured.

12. Virgil-Florin Duma et al. (2009): We achieve the analysis and design of optical attenuators with double-prism neutral density filters. A comparative study is performed on three possible device configurations; only two are presented in the literature but without their design calculus. The characteristic parameters of this optical attenuator with Risley translating prisms for each of the three setups are defined and their analytical expressions are derived: adjustment scale (attenuation range) and interval, minimum transmission coefficient and sensitivity. The setups are compared to select the optimal device, and, from this study, the best solution for double-prism neutral density filters, both from a mechanical and an optical point of view, is determined with two identical, symmetrically movable, no mechanical contact prisms. The design calculus of this optimal device is developed in essential steps. The parameters of the prisms, particularly their angles, are studied to improve the design, and we demonstrate the maximum attenuation range that this type of attenuator can provide.

13. Syed Yaser Habeeb et al.(2012): When using a 3.0 NDF, visual acuity was reduced in all eyes (p _ 0.0001). When using a 0.4 NDF, visual acuity was significantly improved in eyes with strabismic amblyopia compared to unfiltered conditions (p _ 0.0011). There was no significant effect by NDFs on visual field testing in eyes with strabismic amblyopia or fellow non-amblyopic eyes. Neutral density filters affect eyes with strabismic amblyopia differently than they do non-amblyopic eyes. A significant improvement in visual acuity of eyes with strabismic amblyopia was observed when using a 0.4 NDF compared to non-amblyopic eyes. Visual acuity was reduced in amblyopic as well as non-amblyopic eyes when viewing through a 3.0 NDF. No significant change in visual fields was observed when using a 0.4 NDF in amblyopic or non-amblyopic eyes.

14. Ackerson et al. (2013):A method of preventing blooming in a pixel array includes affecting an amount of light that impinges on a photoelectric conversion element by adjusting a

transmissivity of an electrochromic element based on an output of the photoelectric conversion element.

15. Laurent Frey et al (2014): We investigate the most appropriate way to optically characterize the materials and predict the spectral responses of metal–dielectric filters in the visible range. Special attention is given to thin silver layers that have a major impact on the filter's spectral transmittance and reflectance. Two characterization approaches are compared, based either on single layers, or on multilayer stacks, in approaching the filter design. The second approach is preferred, because it gives the best way to predict filter characteristics. Meanwhile, it provides a stack model and dispersion relations that can be used for filter design optimization.

16. Jinghua Han et al. (2016):We investigate the damage characteristics and mechanism of neutral density filters consisting of metal film on K9 glass substrate by 1064-nm pulsed laser. The damage morphologies present marked differences with different laser pulse energies. Specifically, with the increase of laser fluence, the damage pits density increase as well, and at the same time, the cracks appear around the pits and interconnect, which lead to the abscission of film. The damage mechanism has been studied from the viewpoint of embedded impurities in the film. The theoretical results show that the difference between the thermodynamic properties of impurities and film can lead to thermos-elastic stress, which plays important roles in deformation of film, nucleation and propagation of cracks. Last, methods have been proposed to improve the laser damage resistance by controlling the size distribution of impurity particles and increasing the film tensile strength.

17. Krzysztof M. Czajkowski et al. (2017): In this paper we study an application of a stack of glass slides as a broadband neutral density filter with high (> 100 W/cm2) damage threshold. The influence of multiple reflections on the filter transmittance is analyzed with transfer matrix method. The numerical study proves that the filter spectrum is determined by material dispersion and degree of wavelength averaging occurring due to light incoherence and limited measurement resolution. Varying the angle of light incidence can be used to extend the possible optical density range of the filters. The numerical results are verified by spectral measurements with setups containing coherent and incoherent light sources.

18. Priya K et al (2018) : Thin films of ZnS have been vacuum coated on glass substrates at room temperature. The crystal structure and optical properties of the films were studied using X-ray diffractometer (XRD and UV visible spectrophotometer, respectively. The X-ray diffraction patterns showed that films were polycrystalline in nature with cubic structure. The optical band gap was measured close to 3.7 eV. The influence of rate of deposition on the grain size of the films were analyzed.

19. Meena Rani et al. (2019): Sodium Bismuth Borate(NBB) glass doped with transition metal (vanadium, iron, cobalt) with composition 20Na2O.30Bi2O3.(50-x)B2O3.xV2O5(x=0.2,0.3), 20Na2O.30Bi2O3.(50x)B2O3.xFe2O3(0.2≤x≤0.5),20Na2O.30Bi2O3.(50x)B2O3.xCoO(x=5,7.5) were prepared using conventional melt quenching technique. Optical transmission spectra of doped sodium bismuth borate have been recorded in wavelength range 400-700nm. The results showed that the transmittance decrease with increase the content of transition metal in the glass

.This transmission spectra showed that doped Na2O.Bi2O3.B2O3have the characteristics of neutral density filter.

20. Alexander Hein et al(2019): Passive graduated filters with fixed absorption profile are currently used in image recording to avoid overexposure. However, a whole set of filters with prescribed gradients is required to cope with changing illumination conditions. Furthermore, they demand mechanical adjustment during operation. To overcome these deficiencies we present a microfabricated active electrochromic graduated filter which combines multiple functionalities: The overall absorbance, the position of medium transmission as well as the magnitude of its gradient can be tuned continuously by electrical means. Live image control is possible using low operation voltages in the range of ±2 V to reach a high change in optical density ΔOD of 1.01 (400 nm to 780 nm) with a coloration and bleaching time 1.3 s and 0.2 s, respectively. Owing to their low volume and power consumption they are suitable for widespread applications like in smartphones, surveillance cameras or microscopes.

21.Leibovici et al. (2020) :A method comprises disposing a photosensitive film layer on a surface of a substrate layer and placing a variable neutral density (ND) filter such that a surface of the variable ND filter faces an exposure region of the photosensitive film layer. The variable ND filter is a thin film that has an attenuation profile that modulates transmittance of light passing through the variable ND filter to the exposure region to cancel out an uneven power distribution in an intermediate interference exposure pattern at the exposure region of the photosensitive film layer. The method further comprises arranging one or more laser generators such that at least two generated beams of light from the one or more laser generators intersect with each other and form the intermediate interference exposure pattern that is modulated by the variable ND filter to form a target interference exposure pattern at the exposure region.

Objectives of the Study

- Study on PVD suitable metals whose thin films are hard enough for durable ND filter.
- Data analysis on spectral characteristics vs thickness vs evaporation parameter.
- Use of hard dielectric as properties modifier/Protective layer.

Methodology:

Selection of Material:

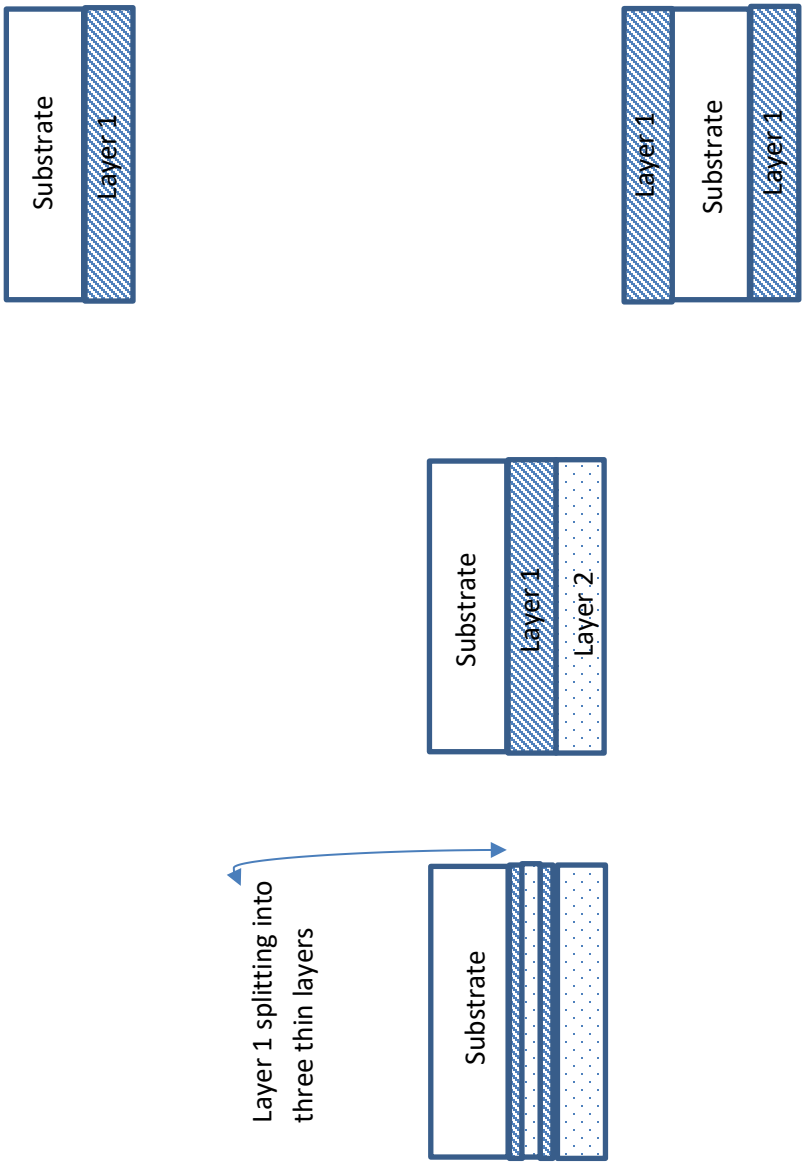
1. Study on thin film absorption characteristics of Ni, Cr, Cu, Al etc for various spectral range.
2. Study on modified absorption characteristics of mixed/compounds of Ni, Cr, Cu, Al etc for minimum 200nm range (viz. for visible 450nm-650nm)
3. Hardness and durability of these metal films particularly for higher density.

Study of PVD suitability

The desired selected materials will be studied for deposition feasibility parameters for single layer

- Absorption vs evaporation parameter
- Absorption vs thickness parameter

Study of parameters with various combination a



Fabrication of ND Filter

ND Filter will be simulated using single layer optimized parameters and optimized for fabrication.

Characterization:

- Optical properties (UV-Vis-IR), Morphology (AFM, SEM)etc.

Scopes & Relevance of Study

These ND filters can be used in spectroscopy as well as photography in visible region 400-700nm.

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Signature of Candidate **Signature of Supervisor**

Signature of Chairperson